6-G
ASSESSMENT OF BUOYANT MATERIALS AND THE MICROLAYER

**FINAL
ENVIRONMENTAL
IMPACT STATEMENT**

**Brightwater
Regional Wastewater
Treatment System**

APPENDICES

Brightwater
King County TREATMENT SYSTEM

Final

Appendix 6-G
Assessment of Buoyant Materials and the Microlayer

August 2003

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King County
Department of Natural Resources and Parks
Wastewater Treatment Division

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1.0   Introduction

King County has prepared a Draft Environmental Impact Statement (Draft EIS) and Final Environmental Impact Statement (Final EIS) on the Brightwater Regional Wastewater Treatment System. The Final EIS is intended to provide decision-makers, regulatory agencies and the public with information regarding the probable significant adverse impacts of the Brightwater proposal and identify alternatives and reasonable mitigation measures.

King County Executive Ron Sims has identified a preferred alternative, which is outlined in the Final EIS. This preferred alternative is for public information only, and is not intended in any way to prejudge the County's final decision, which will be made following the issuance of the Final EIS with accompanying technical appendices, comments on the Draft EIS and responses from King County, and additional supporting information. After issuance of the Final EIS, the King County Executive will select final locations for a treatment plant, marine outfall and associated conveyances.

The County Executive authorized the preparation of a set of Technical Reports, in support of the Final EIS. These reports represent a substantial volume of additional investigation on the identified Brightwater alternatives, as appropriate, to identify probable significant adverse environmental impacts as required by the State Environmental Policy Act (SEPA). The collection of pertinent information and evaluation of impacts and mitigation measures on the Brightwater proposal is an ongoing process. The Final EIS incorporates this updated information and additional analysis of the probable significant adverse environmental impacts of the Brightwater alternatives, along with identification of reasonable mitigation measures. Additional evaluation will continue as part of meeting federal, state and local permitting requirements.

Thus, the readers of this Technical Report should take into account the preliminary nature of the data contained herein, as well as the fact that new information relating to Brightwater may become available as the permit process gets underway. It is released at this time as part of King County's commitment to share information with the public as it is being developed.

The purpose of this TM is to assess potential effects of the proposed Brightwater WWTP discharge on sea surface contamination and shoreline accumulation. This assessment includes both quantitative and qualitative analysis of the proposed discharge's effects on the microlayer and adjacent shorelines.

2.0   Executive Summary

The purpose of this Technical Memorandum (TM) is to assess potential effects of the proposed Brightwater WWTP discharge on sea surface contamination and shoreline accumulation. The sea surface microlayer is a complex air-seawater boundary that provides critical habitat for an abundant assemblage of organisms. Substances of natural and anthropogenic origin, including amino acids, proteins, fatty acids, lipids, phenols, and a variety of other organic compounds concentrate on the water surface through atmospheric deposition, runoff, direct discharges (spills, vessel discharges, etc.), rising air bubbles and floatation of constituents in the water column.

The higher levels of particulates and natural compounds in the sea surface microlayer can sequester or absorb trace metals and organic compounds. Current scientific research suggests that the surface concentrations of both organic and inorganic contaminants may be at levels that are toxic to embryos and larvae of important fish and invertebrates that inhabit the microlayer in Puget Sound. However, the specific sources and effects of sea surface contamination in Puget Sound remain largely unknown. There are no data that quantify the relative contribution of all potential sources to the sea surface microlayer.

Within treated wastewater effluent is a buoyant fraction known as floatage consisting of fats, oils and grease, as well as constituents that may sorb onto the floatage. Dissolved and neutrally buoyant constituents from deep wastewater outfalls such as the proposed Brightwater outfall generally remain at depth in Puget Sound for an extended period. However, the buoyant floatage may gradually rise to the sea surface from a submerged wastewater plume.

Once floatage from submerged wastewater plumes reaches the sea surface, it combines with other microlayer contaminants. The resulting composite microlayer is subjected to several mechanisms of horizontal transport, including gravity spreading, tides, and wind. The ultimate fate of sea surface contaminants includes (1) deposition on the shorelines of Puget Sound, (2) transport out of Puget Sound to the Strait of Juan de Fuca, Georgia Strait and the Pacific Ocean, (3) degradation by physical, chemical or biological processes such as sunlight, bacterial degradation or oxidation/reduction, or (4) movement into the atmosphere through the bursting of bubbles that forms a sea-salt aerosol.

There is no known quantification or partitioning of sea surface floatage or microlayer contaminants of concern among these receptors. Additionally, no studies have linked these receptors to specific sources of microlayer sources in Puget Sound.

A mathematical model was developed to simulate the path of floatage discharged from the proposed Brightwater outfall zones (6 and 7S). Floatage will take up to five days to reach the water surface after discharge from the outfall diffuser. To simulate the transport of floatage during its ascent, the model uses drogue (current drifter) data from releases in the Point Wells vicinity to simulate the 2-dimensional trajectory. The trajectories from 24 individual drogue releases combined with predicted rates of ascent predicted the positions of multiple buoyant particles when they reach the water surface. Physical, chemical, and biological decay processes that would likely occur during the five-day ascent period have not been studied. Thus, these processes are not quantified and model results are judged to be very conservative.

The resulting plume at the water surface would occupy an area of 180 square kilometers, which occupies most of the Triple Junction region of Puget Sound. Using conservative criteria for the daily mass of floatage discharged from the proposed outfall, the surface accumulation rate would be approximately 5 mg/m^2/day over this area. Areal concentration is calculated rather than volumetric concentration because the thickness of the microlayer is variable and the horizontal flux of material after surfacing is unknown. To achieve realistic predictions of volumetric concentrations in the surface microlayer, a quantitative description of the microlayer thickness, horizontal transport mechanisms, and concentration gradients within the microlayer would be required. These descriptions are beyond the current state of knowledge.

Once at the water surface, floatage will be transported by winds, tidal currents, and density-driven currents (estuarine circulation produced by density differences between river runoff and

ocean water). The predominant net transport will be directly out of Puget Sound, aided by surface density currents opposing transport southward into Puget Sound or northward into Possession Sound. The outgoing surface current may be opposed or aided by wind-driven currents at any time. The predominant wind directions are from the northwest during summer creating direct onshore transport of floatage, and from the south during winter producing net seaward transport.

3.0 Concerns Regarding the Sea Surface Microlayer

3.1 Sea Surface Microlayer

The top layer of the ocean surface, approximately one to 1000 micrometers (µm) in thickness, is referred to as the sea-surface microlayer. The sea surface microlayer is a complex air-seawater boundary where unique physical, chemical, and biological processes take place. Studies show that the sea surface is a highly productive and metabolically active interface that provides habitat for an abundant assemblage of organisms (Hardy, 1997; GESAMP, 1995).

Many organisms live in and find food in this layer at levels significantly elevated from that of the waters beneath. Organisms live, reproduce, or feed in the surface layers. Species of algae, bacteria, phytoplankton, zooplankton, and fish can be permanent inhabitants of the surface layer. The eggs and larvae of a large number of invertebrates and fish, such as cod, sole, flounder, rockfish, and halibut, utilize the sea surface during a portion of the embryonic and larval development. The microlayer also functions as an interface for gas and particulate exchange and has a role in the transfer of heat and momentum between the ocean and atmosphere (GESAMP, 1995).

Below the air/water interface the aquatic surface layer consists of a series of sublayers with varying thicknesses. The sublayers includes a thin surface nanolayer ($\sim{<}1\mu m$) that has concentrations of surface-active compounds, the surface microlayer ($\sim{<}1000\mu m$) with high concentrations of particles and microorganisms, and the surface millilayer ($\sim{<}10\mu m$) that has small animals and fish and invertebrate eggs and larvae (Hardy, 1997).

Surface-active substances of natural and anthropogenic origin often concentrate in the sea surface. These substances, including amino acids, proteins, fatty acids, lipids, phenols, and a variety of other organic compounds derived from biota in the water column, concentrate on the water surface through rising air bubbles and floatation. Organic compounds of natural origin are the principal film-forming components in the aquatic system and influence the presence of other microlayer substances (GESAMP, 1995).

The concentration or accumulation of these chemical compounds modifies the physical and optical properties of the sea surface. Currents and wind can increase or decrease the accumulation and concentrations of substances in the microlayer. The accumulation can form organic films, that increase the surface tension to such an extent that the transfer of chemical compounds, heat, and momentum between the water and atmosphere is affected (GESAMP, 1995).

The higher levels of particulates and natural compounds in the sea surface microlayer can sequester or absorb trace metals and organic compounds. Research suggests that the surface concentrations of both organic and inorganic contaminants may be at levels that are toxic to

embryos and larvae of important fish and invertebrates that inhabit the microlayer in Puget Sound (Hardy, 1987). However, the specific sources and effects of sea surface contamination in coastal waters, including Puget Sound, remains largely unknown (EPA, 1990; Herrera, 2002).

3.2   Sources and Pathways

Contaminants reach the sea surface microlayer via potential pathways including atmospheric deposition, floatation of organic material in the water column, and from land sources via runoff (GESAMP, 1995). Atmospheric sources include a wide range of anthropogenic air pollutants. Sources from the water column include organic compounds (carbohydrates, proteins and lipids) released from biota and sediments. Direct discharges to the water surface include rivers, stormwater, combined sewer overflows (CSOs), industrial discharges, spills, and recreational and commercial vessel emissions. Indirect discharges may include buoyant constituents from deep wastewater outfalls, releases from contaminated sediment sites, and sediment disturbances that rise to the sea surface.

Little else is known about the sources and pathways of sea surface contaminants. There is substantial data on the presence of microlayer contaminants in the potential sources, but few studies have linked the pathways, transformations, or even the presence of sea surface contaminants to specific sources or source categories. There are no data that quantify the relative contribution of each of the potential sources to the sea surface microlayer (EPA, 1990; GESAMP, 1995; Herrera, 2002).

Increases in worldwide population and industrialization have resulted in greater quantities and types of chemicals entering the ocean as a direct discharge or through atmospheric transport and deposition. Many pollutants are surface active and can increase the incidence of films or slicks, as well as increase the concentration of surface active or toxic substances at the ocean surface (GESAMP, 1995). Trace organic compounds of human origin, including polychlorinated biphenyls, chlorinated pesticides, and hydrocarbons have been measured in Puget Sound microlayer samples (Hardy, 1987), yet undetected in bulk water samples from the water column.

Twenty-nine municipal wastewater treatment plant outfalls discharge to the Main Basin of Puget Sound (Tacoma Narrows to Admiralty Inlet) (Health, 1996). All are designed to provide secondary treatment. Within the effluent is a buoyant fraction known as floatage consisting of fats, oils and grease, as well as any constituents that may sorb onto the floatage. Most wastewater treatment plant (WWTP) outfalls in Puget Sound are relatively shallow, and their buoyant effluent plumes typically reach the water surface within minutes after discharge. However, wastewater plumes from deep outfalls in Puget Sound (e.g., King County's existing WWTP outfalls) are trapped and remain well below the water surface by the stratification (i.e., density layering) in Puget Sound. Dissolved and neutrally buoyant constituents generally remain at the trap depth in Puget Sound for an extended period (Bendiner, 1976; Ebbesmeyer, 1987; Cokelet, 1988). However, the buoyant floatage from any depth of outfall may eventually rise to the sea surface from a submerged wastewater plume.

3.3   Transport and Fate in the Microlayer

Once floatage from submerged wastewater plumes reaches the sea surface, it combines with other microlayer contaminants. The relative contribution of floatage from submerged wastewater plumes to all potential sources is unknown (EPA, 1990; Herrera, 2002). The resulting composite microlayer is subjected to several mechanisms of horizontal transport. The principal transport mechanisms include gravity spreading, tides, and wind.

The physical, chemical, and biological processes that assimilate or transform sea surface contaminants are not well known. The ultimate fate of sea surface contaminants includes (1) deposition on the shorelines of Puget Sound, (2) transport out of Puget Sound to the Strait of Juan de Fuca, Georgia Strait and the Pacific Ocean, (3) degradation by physical, chemical or biological processes such as sunlight, bacterial degradation or oxidation/reduction, or (4) movement into the atmosphere through the bursting of bubbles that forms a sea-salt aerosol (GESAMP, 1995). There is no known quantification or partitioning of sea surface floatage or microlayer contaminants of concern among these receptors. Additionally, no studies have linked these receptors to specific sources of microlayer sources in Puget Sound.

3.4   Purpose of this Technical Memorandum

The purpose of this Technical Memorandum is to assess potential effects of the proposed Brightwater WWTP discharge on sea surface contamination and shoreline accumulation. This assessment includes both quantitative and qualitative analysis of the accumulation of effluent constituents from the proposed discharge on the sea surface microlayer and adjacent shorelines.

4.0   Proposed Wastewater Discharge

4.1   Wastewater Treatment Facilities

King County proposes to build a new wastewater treatment plant to serve residents of north King County and south Snohomish Counties. The plant would have the capacity to treat an average wet-weather flow of 36 million gallons per day (mgd) by 2010 (phase 1), increasing to 54 mgd by 2040 (phase 2). The preferred alternative for the treatment plant would provide secondary treatment through a split flow membrane bioreactor (MBR) process. The process feature uses membrane bioreactors up to a threshold flow, followed by ballasted sedimentation for the intermittent peak flows. Disinfection would be provided by sodium hypochlorite solution. Dechlorination facilities would be provided, but used only if necessary to meet National Pollution Discharge Elimination System (NPDES) permit limits (Goetz, 2003).

4.2   Effluent Design Criteria

The NPDES permit for the new treatment facility will include effluent limits. Technology-based effluent limits for municipal wastewater treatment plants must comply with section 40 of the Code of Federal Regulation (CFR) Part 133 and Washington Administrative Code (WAC) 173-221. The technology-based limits include pH, BOD_5, suspended solids, and fecal coliform bacteria. Ecology may also include water quality-based limits if necessary to meet water quality

standards in WAC 173-201A or sediment standards in WAC 173-204. The only water quality-based limit in the Brightwater NPDES permit is anticipated to be for chlorine (Goetz, 2003).

4.3   Floatage in Secondary Effluent

Secondary treated wastewater contains a fraction of buoyant (floatable) materials, termed floatage. Floatable particulate matter from wastewater effluent is primarily composed of oils, greases, and wax particulates. Floatage contributed from other sources may also be composed of plastic, fiber, rubber, wood, seeds, vegetative material, and unidentifiable tissue and debris. Bacteria, pathogens, and toxicants from wastewater may be associated with these floatable particulates.

The vertical transport of wastewater floatage was studied in laboratory experiments conducted by Word, et al. (1984). Their studies attempted to simulate the discharge, at depth, of secondary treated wastewater to marine waters. Density stratifications were established in large tanks of seawater (1118 liters) and wastewater effluent was introduced into the bottom of the tank. Floatage, collected from the surface and quantified, was estimated to comprise 10-20 percent of the total suspended solids (TSS) in secondary effluent.

4.4   Mass Discharge

The technology-based TSS limit in Brightwater's NPDES permit is expected to be 30 milligrams per liter (mg/L) for the maximum monthly average, and 45 mg/L for the maximum weekly average. These limits are typical of secondary treatment processes and are considered conservative of projected treatment plant performance. The proposed membrane bio-filter treatment process is expected to produce effluent with TSS concentrations well below the 30 mg/L monthly limit and minimize floatage. Tests were conducted at King County's South Treatment Plant to compare conventional activated sludge to the proposed membrane bio-filter technology (Parametrix, 2003). This analysis was conducted for constituents of the greatest potential concern for their effects on aquatic life. The analysis confirmed that effluent quality with the proposed membrane technology would be significantly better than conventional activated sludge effluent quality. It is estimated that annual mass loads to Puget Sound from the proposed Brightwater discharge will be reduced by about 40 to 90 percent, depending on the chemical, using membrane treatment rather than conventional activated sludge treatment.

Accumulation of wastewater floatage at the water surface and shorelines is a chronic exposure concern rather than acute or event-oriented. An appropriate time scale over which to evaluate impacts on the sea surface microlayer and shoreline accumulation is monthly. Therefore, the wet weather design flows for 2010 and 2040 were used to project mass discharge of TSS and floatage. Conservatively utilizing the expected NPDES permit monthly limitation on TSS, Table 1 summarizes the projected flow, TSS, and floatage mass discharge for phase 1 and phase 2.

Table 1.
Effluent Flow, TSS, and Floatage Discharge Projections

	Year 2010	Year 2040
Average Wet Weather Flow (mgd)	36	54
Maximum Month TSS Concentration (mg/L)	30	30
Assumed TSS Mass Discharge (lbs/day)	9,007[1]	13,510[1]
Floatage/TSS Ratio	0.15	0.15
Assumed Floatage Mass Discharge (lbs/day)	1,351	2,027

[1] Mass discharge (lbs/day) = Flow (mgd) x Concentration (mg/L) x 8.34 lbs/gallon

4.5   Outfall and Diffuser Description

Conceptual outfall alignments for two outfall zones, designated 6 and 7S, have been developed for the potential Brightwater treatment plant sites. These candidate zones are shown in Figure 1. Both sites are located offshore from the eastern shoreline of Puget Sound in the vicinity of Point Wells and Edwards Point. The proposed outfall would extend approximately 5,000 feet offshore to water depths of about 600 feet, terminating in a 500-foot multi-port diffuser.

5.0   Theoretical Sea Surface Accumulation Rate

5.1   Model Description

King County has collected extensive oceanographic data in the proposed outfall discharge vicinity, which were used in this analysis to predict the fate and transport of floatage from a Brightwater treatment plant. A mathematical model was developed to simulate the path of floatage discharged from the outfall following the initial buoyant mixing phase. Because currents are continuously varying, the position of an effluent element or "particle" is a stochastic variable within the model. To simulate the transport of floatage during its ascent, the model uses drogue data to simulate the 2-dimensional trajectory, combined with vertical velocities from literature to predict the position of a particle when it reaches the water surface.

Independent variables in the floatage model include (1) the pathline simulated by drogue data, (2) depth of the effluent plume at the conclusion of the initial mixing phase, and (3) the rise time of buoyant constituents. The resulting positions of effluent particles when they "hit" the water surface were recorded for all combinations of these variables. The results were overlaid on a grid of cells measuring 0.01 degree latitude by 0.01 degree longitude (approximately 3,600 feet by 2,400 feet). Model boundaries are Admiralty Inlet, Possession Sound, and West Point. The "hits" in each grid cell or model boundary are summed and divided by the total number of "releases." The results represent the fraction of the floatage predicted to reach the water surface (microlayer) in each grid cell.

Both outfall sites, 6 and 7S, are relatively near each other compared to the scale of the study area. Both sites are located on the floor of the main basin of Puget Sound, which is practically the deepest potential site available for locating the diffuser. Projected submergence depths for the effluent plumes from each site are similar. The sites are also approximately the same distance from the eastern shoreline. Therefore, the projected impacts of each site on microlayer concentrations and shoreline impacts are similar. The modeling, which is based on drogue trajectories released in the general vicinity of both, represents both candidate diffuser sites.

4.2   Initial Plume Dilution and Submergence

The effluent plume was modeled using the EPA computer model PLUMES (Baumgartner et al., 1993). The PLUMES submodel UM predicted the initial dilution, plume dimensions, and the trapping depth (depth at which the plume reaches neutral buoyancy and ceases to rise, due to the ambient density stratification). Dilution modeling results for the 500-foot long diffuser alternatives at sites 6 and 7S are provided in *Predesign Initial Dilution Assessments* (King County, 2003). Independent variables in the plume modeling included (1) ambient density profiles from February and July, (2) representative current speeds, and (3) the range of projected effluent flow rates. The resulting 10th, 30th, 50th, 70th, and 90th percentile values for plume submergence are provided in Table 2. These values represent five median submergence depths of equal probability.

Table 2.
Plume Submergence Depths

Percentile	Submergence Depth (m)
10th	70
30th	86
50th	96
70th	105
90th	122

5.3   Vertical Transport and Dispersion of Floatage

A significant benefit of a deep trapping depth with the proposed diffuser is the time it takes for the floatage to rise to the water surface. The laboratory studies by Word et al (1984) identified a median upward velocity of approximately 2 meters per hour, with a range of 1-4 meters per hour. The distribution of floatage rise velocity used in this analysis is shown in Table 3. Similar to the dilution and submergence statistics above, each velocity represents an equal probability. The lower and upper velocities measured by Word et al are estimated as the 10th and 90th percentile values. The 30th and 70th percentile values are taken as the arithmetic averages of the 10th and 50th, and 50th and 90th percentiles, respectively.

Table 3.
Floatage Rise Velocities

Percentile	Vertical Velocity (m/hr)
10th	1
30th	1.5
50th	2
70th	3
90th	4

The submergence depths and rise velocities suggest that floatage requires a travel time of 17 to 122 hours to reach the water surface from the trapping depth of the effluent plume. Additional mixing and dispersion of buoyant materials would occur during this ascension phase, but this mechanism is neglected in this modeling (a conservative assumption). Other processes that may occur during this ascendancy phase are not considered, including biodegradation, flocculation, and settling.

5.4 Particle Trajectory

Drogues released for the oceanographic studies (Ebbesmeyer, 2002) were used to simulate the 2-dimensional trajectories of floatage "particles." Drogues were 10 meter deep vanes released at selected depths and locations representing alternative diffuser locations. The vanes were tethered to surface floats that transmitted positions via satellite every 30 minutes. Drogue data were summarized in *Final Report, Puget Sound Physical Oceanography* (Ebbesmeyer, 2002), and the drogue data obtained from CD Appendix C of the report.

All drogue release points for the oceanographic studies are shown in Figure 2. The drogues used in this analysis are only those released from the Point Wells and Edwards Point deep sites. A total of 25 drogue releases were selected that met these criteria.

5.5 Model Results

The sea-surface position at which floatage would reach the water surface was modeled for each combination of drogue trajectory, submergence depth, and rise velocity, as described previously, for a total of 449 discrete positions. Positions outside the model boundaries (West Point, Admiralty Inlet, and Possession Sound) were summed as well as for each model grid element.

Had all drogue data been of duration greater than the maximum rise time, there would have been a possible 600 discrete positions (24 drogue releases x 5 trapping depths x 5 rise velocities). However, several of the drogue releases were grounded or recovered before the full rise time had elapsed. For those cases where the drogue record is shorter than the required floatage rise time, the results were not included in the model results. The affect of this disregard for missing data is

to bias the results of the model to shorter rise times and shorter distances from the proposed diffuser sites. The longer rise times that were excluded from the model results would have shown greater dispersion. Therefore, the model results are conservative, and actual dispersion would be greater than predicted by the model.

The results, presented in Figure 3, show the total number of hits within each 3,600-foot by 2,400-foot grid cell. Twelve (2.6 percent of the hits) lay outside the model boundaries, with six (1.3 percent) exiting through Admiralty Inlet, six (1.3 percent) to Possession Sound, and zero passing south past West Point.

5.6   Concentration at the Water Surface

Areal concentration (in mg/m^2/day) is calculated rather than volumetric concentration because the thickness of the microlayer is variable and the horizontal flux of material after surfacing is unknown. To achieve realistic predictions of volumetric concentrations in the surface microlayer, a quantitative description of the microlayer thickness, horizontal transport mechanisms, and concentration gradients within the microlayer are required. These descriptions are beyond our current state of knowledge.

The model results in Figure 3 represent the tidally averaged "footprint" of floatage at the water surface. The total area potentially occupied by this footprint is 180 square km, approximately 50% of the 365 km^2 area modeled. Dividing the maximum projected mass discharge of floatage (year 2040 projection) into this area yields a gross areal accumulation rate of 5.11 mg/m^2/day. The concentration for each cell is shown in Figure 4, ranging from 2 to approximately 50 mg/m^2/day.

6.0   Transport at the Water Surface

Once the floatage surfaces, it will be transported in a direction and at speeds controlled primarily by wind, estuarine circulation, and tidal currents (oscillatory tidal motion). It is possible that intertidal beaches may be the ultimate receptor of a portion of the sea surface contaminants.

6.1   Wind-Driven Transport

After floatage reaches the sea surface, it will eventually be transported toward open water or downwind beaches. Predominant wind directions over North Puget Sound waters are from the north during April through October and from the southeast during November through March. The mean wind speed across the water is approximately 6 feet per second, producing surface currents of approximately 0.2 feet per second in the same direction (Ebbesmeyer et al., 1984).

Wind-driven shoreward transport has been simulated by using long-term wind data from Paine Field and surface concentrations from the modeling presented above. The wind directional frequencies for Paine Field from January 2000 through December 2002 are shown in Table 4. Shoreline contact was simulated by transporting each surface hit from the floatage modeling to adjacent shorelines. The direction of transport was partitioned by the percentage of wind events that occurred in each of the directional bins indicated by the wind rose. The resulting rates at which floatage would be delivered to the shorelines is shown in Figure 5.

Table 4.
Wind Direction Data from Paine Field

Direction	Frequency (%)
N	19.3
NW	12.8
W	6.1
SW	7.1
S	18.0
SE	26.8
E	5.2
NE	4.7

Predominant wind-driven transport directions are toward the eastern and southeastern shorelines by north and northwest winds, and toward Admiralty Inlet during prevailing south and southeast winds. The western shoreline of the study area is minimally affected by wind-driven transport because winds from the east and northeast are rare at this location. Likewise, direct onshore transport by wind to the northeast (Possession Sound) is unlikely due to the prevailing wind directions. The only way to potentially mitigate for wind-driven onshore transport is horizontal separation of the outfall plume from the shoreline. However, the proposed diffuser sites maximize the practicable distance of the outfall plume from the shoreline and would therefore minimize any effects of floatage on the adjacent eastern shoreline. The only potential other means of mitigating microlayer or shoreline impacts would be in source control or treatment.

6.2   Tidal Currents

Tidal currents are those created by the ebb and flood of the tide. Tidal currents during the period of transport from the point where floatage surfaces to the shoreline were omitted in the results presented in Figure 5, because (except for eddies) tidal currents are generally longshore and oscillatory. Thus, the net effect of tidal currents on shoreward transport of floatage once it reaches the sea surface is secondary to wind. The principal influence of tidal currents occurs during vertical transport to the sea surface, which is implicit in the modeling presented in Figures 2 and 3.

6.3   Density Currents and Net Transport

Puget Sound is an estuarine fjord consisting of several deep basins, with narrow channels and side embayments, separated by relatively shallow sills. The proposed Brightwater WWTP

outfall is located in the northern Main Basin of Puget Sound. The Main Basin is the largest and most seaward of all the Puget Sound basins, bounded by Admiralty Inlet to the north (Puget Sound's entrance sill) and the Tacoma Narrows to the south. The Whidbey basin lies to the northeast, linked to the Main Basin by Possession Sound.

The Main Basin exhibits a typical estuarine two-layer net circulation pattern driven by density gradients. Surface waters are driven seaward by the inflow of buoyant river waters, overlying a landward-flowing lower layer of dense (cooler and more saline) ocean water pulsed over the Admiralty Inlet sill during flood tides (Cokelet et al., 1985; Cokelet et al., 1988). These circulation dynamics are also described extensively in the King County oceanographic studies report (Ebbesmeyer et al., 2002). The schematic net circulation in this area is depicted in Figure 6, which is reprinted from the oceanographic report.

The proposed Brightwater outfall is located in the "triple junction," where Admiralty Inlet, Possession Sound, and the Main Basin intersect. Figure 6 shows that, on a net basis, floatage discharged in the triple junction will be transported out of Puget Sound through Admiralty Inlet due to the density currents described above. Due to the high runoff volumes from the Snohomish, Stilliguamish, and Skagit Rivers, Possession Sound has a particularly strong density current at the surface that would strongly inhibit floatage from being transported into Possession Sound from the triple junction. The wind-driven transport results simulated in Figure 5 are conservative, because they omit the effect of density currents that would tend to drive surface materials out Admiralty Inlet.

6.4   Drift Card Studies

Drift cards are small surface drifters released from selected candidate outfall locations. Their shoreline recovery locations were tracked and recorded. Figure 7 (from Ebbesmeyer, 2002) shows the Point Wells/Edwards Point release sites and the shoreline locations where they were recovered. Most of the cards were recovered north of the release site and in Admiralty Inlet. Relatively few were recovered in Possession Sound or south of the release site. These observations are consistent with the net transport regime described above, which suggests most of the floatage will be transported out of Puget Sound through Admiralty Inlet.

7.0   Factors Not Considered in the Theoretical Accumulation Rates

The floatage model presented above is very (perhaps overly) conservative. It does not account for potentially significant processes that may influence deeply discharged wastewaters. The quantitative assessment above is based on the previously described laboratory experiments by Word et al. (1984). Extrapolation of their experimental laboratory chambers to wastewater floatage discharged at depth in Puget Sound has several limitations that may tend to exaggerate the potential for effluent to reach the sea surface.

7.1   Limitations in Extrapolation of Laboratory Results

The first of the limitations is that the rise of floatage in the small laboratory tank (1.1 m^3 in volume) was measured in minutes, versus days for deep outfalls in Puget Sound. Therefore, the

decomposition or microbial breakdown of floatage and associated toxicants of concern may significantly alter their physical and chemical character. Such aging processes have not been replicated in existing laboratory studies of floatage and, therefore, the ultimate fate of such material remains unclear.

7.2   Effect of Pressure at Point of Discharge

Another potentially important physical factor involved in actual effluent discharges versus laboratory experiments is pressure. Effluent discharged at a depth of 600 feet is subjected to 18 atmospheres of pressure versus only one atmosphere for laboratory experiments. The influence of extreme pressure experienced by the floatable materials has not been researched. However, such pressure could reasonably be expected to alter the fate of such material through mechanical processes (crushing cellular, microbial, viral or molecular structures of floatage or contaminants of concern).

7.3   Assimilation and Decay

Decay and modification of the floatage by flocculation, interception, assimilation by biological organisms, or bacterial degradation during the ascent to the water surface was not considered in this quantitative analysis. The theoretical surface concentrations presented in Figure 4 assumes that all of the discharged floatable matter reaches the water surface without any physical or biological transformation.

Coagulation of materials also occurs when wastewater effluent is discharged to marine waters. During this process, the particulate matter tends to stick together with itself and ambient particles in the seawater, increasing the particle size. In actual practice, this coagulation process may act to increase the particulate density and effectively reduce the amount of floatage that reaches the water surface.

Finally, the sinking of biogenic particles (e.g., detritus, natural fecal pellets) can act to remove metals, organics, nutrients, and other contaminants of concern from the water column (Olsen et al., 1982). Such removal processes have generally been ignored in studies of wastewater particulates discharged to Puget Sound.

8.0   Summary

The proposed wastewater treatment plant and outfall will minimize the effects of the effluent discharge on the sea surface microlayer. The proposed treatment facilities will provide state-of-the-art treatment of all wastewater parameters, including floatage and the potential contaminants that may associate with the floatage.

The proposed deep diffuser will dilute and trap the effluent plume in deep water within the Triple Junction region of Puget Sound. Dissolved constituents in the effluent will remain at the trapping level of the effluent plume. However, buoyant materials (floatage) in the effluent will rise in the water column and reach the water surface. Physical, chemical, and biological processes may inhibit vertical rise of contaminants, and/or assimilate the contaminants during the vertical rise phase. There are no field studies that have quantified the rate of accumulation of floatage or other microlayer contaminants from deep water outfalls.

Once at the water surface, floatage will be transported by winds, tidal currents, and density-driven currents (estuarine circulation produced by density differences between river runoff and ocean water). The predominant net transport will be directly out of Puget Sound, aided by surface density currents opposing transport southward into Puget Sound or northward into Possession Sound. The density currents may be opposed or aided by wind-driven currents depending on the predominant wind directions. The predominant wind directions are from the northwest during summer creating direct onshore transport of floatage, and from the south during winter producing net seaward transport.
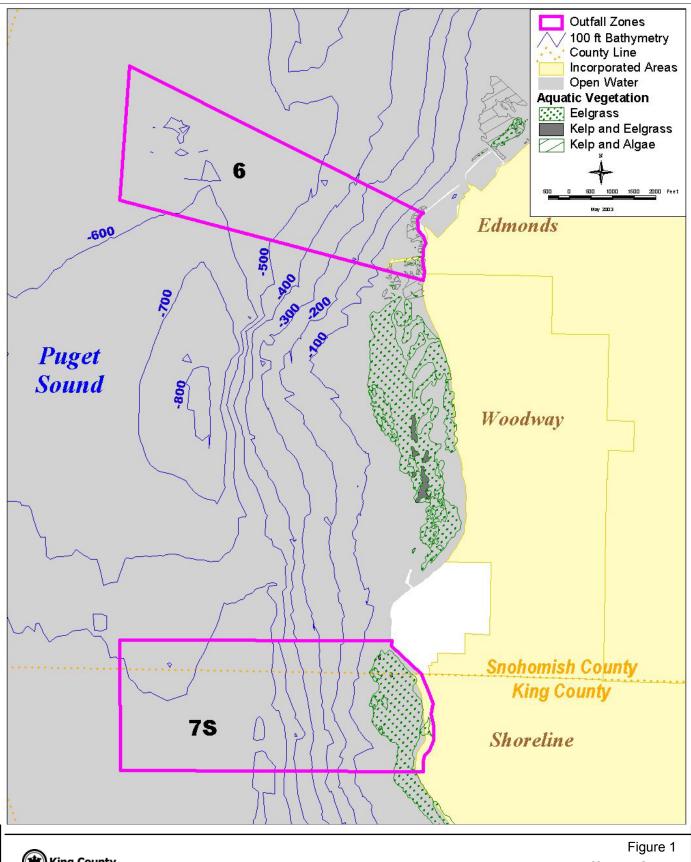
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List of Figures

Legend

- Outfall Zones
- 100 ft Bathymetry
- County Line
- Incorporated Areas
- Open Water

Aquatic Vegetation
- Eelgrass
- Kelp and Eelgrass
- Kelp and Algae

N

500 0 500 1000 1500 2000 Feet

May 2003

Puget Sound

6

-600

-700

-500

-400

-300

-200

-100

-800

Edmonds

Woodway

Snohomish County

King County

Shoreline

7S

King County
Department of Natural Resources and Parks
Wastewater Treatment Division

File Name: TM09XF0X
Prepared by: Bruce Nairn

Figure 1
Alternative Diffuser Sites
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM

Whidbey Island

Elliot Point

Point No Point

✈ **Paine Field**

Picnic Point

Kitsap Peninsula

Browns Bay

Whidbey Shoal

Apple Cove Point

Edwards Point

N

Point Wells

Point Jefferson

Jefferson Shoal

Richmond Beach

Boeing Creek

Point Monroe

Pipers Creek

Meadow Point

Bainbridge Island

West Point

50m, 100m, 200m, 150m (contour labels)

25 m Contour Interval
- ⚪ Release A
- 🔴 Release B
- 🟢 Release C
- 🔵 Release D
- 🔵 Release E
- 🔴 Release F
- 🟡 Release G
- 🟠 Release H
- 🔵 Release I
- 🔵 Release J
- ⚫ Release K
- 🔴 Release Dye 1
- 🟢 Release Dye 2
- 🔵 Release Dye 3
- 🔵 Release Dye 4
- 🟣 Release Dye 5
- 🟢 Student (Burcal, 2001)
- Primary Bathymetry Interval
- Secondary Bathymetry Interval
- Shoals

Figure 2
Drogue Release Locations
*BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM*

Figure 3
Surface Hits from Floatage Model
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM

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Department of Natural Resources and Parks
Wastewater Treatment Division

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Whidbey Island

Point No Point

47°54'

Kitsap Peninsula

Browns Bay

Apple Cove Point

Edwards Point

N

Point Wells

Richmond Beach

Legend:
- 2 - 9 mg/m^2/day (pink)
- 9 - 19 mg/m^2/day (blue)
- 19 - 32 mg/m^2/day (light blue)
- 32 - 52 mg/m^2/day (green)
- (gray)

0   2.5   5   Miles

Figure 4

Floatage Concentration at the Water Surface
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM

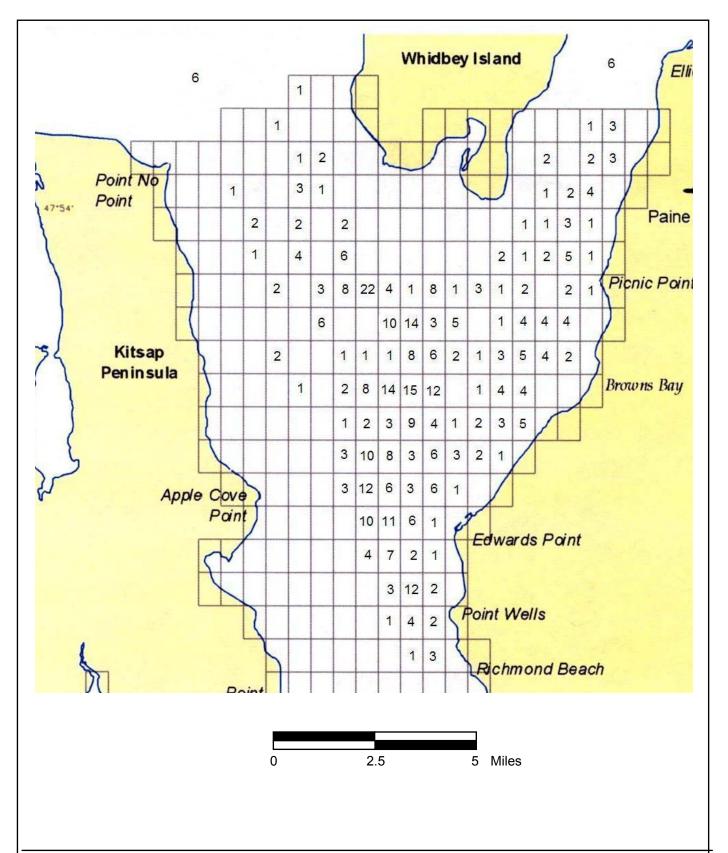**King County**
Department of Natural Resources and Parks
Wastewater Treatment Division

File Name: TM09XF0X
Prepared by: Bruce Nairn

35 kg/day into Possession Sound

142 kg/day through Admiralty Inlet

Whidbey Island

Elliot Point

20.8

9.6

8.8

Paine Field

Point No Point

22.1

Picnic Point

27.8

Kitsap Peninsula

22.9

Browns Bay

7.9

33.9

Apple Cove Point

Edwards Point

11.0

Point Wells

1.8

Richmond Beach

Point Jefferson

2.4

Boeing Creek

Pipers Creek

0.3

19.3

Meadow Point

20 kg/day passed West Point

Bainbridge Island

West Point

N
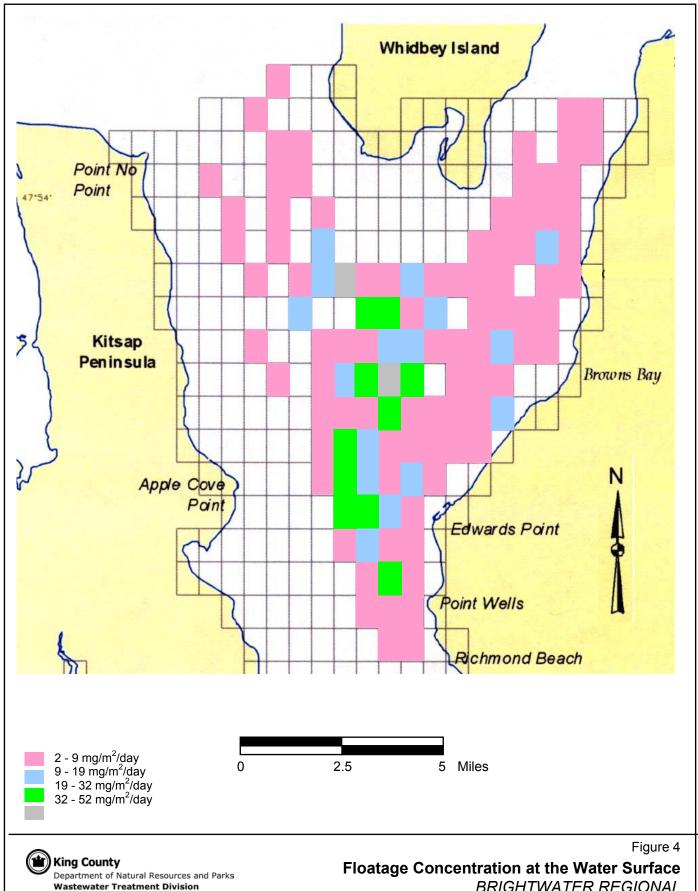
= kg/day/mi of shoreline

0   2.5   5   Miles

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Department of Natural Resources and Parks
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Figure 5

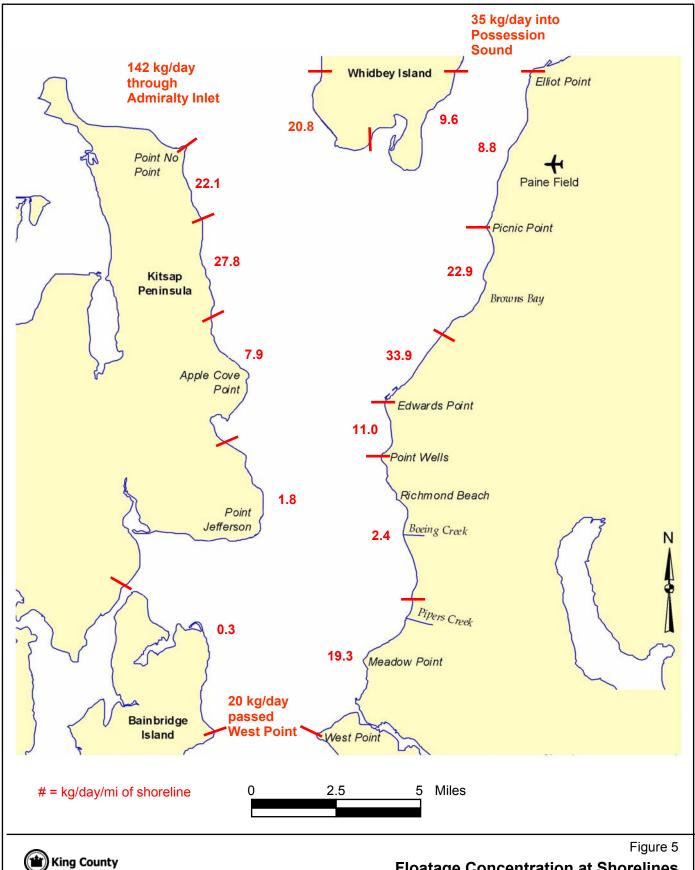**Floatage Concentration at Shorelines**
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM

Solid vectors = Surface Flow
Dashed Vectors = Deep Flow

SOURCE: Ebbesmeyer, 2002

Figure 6
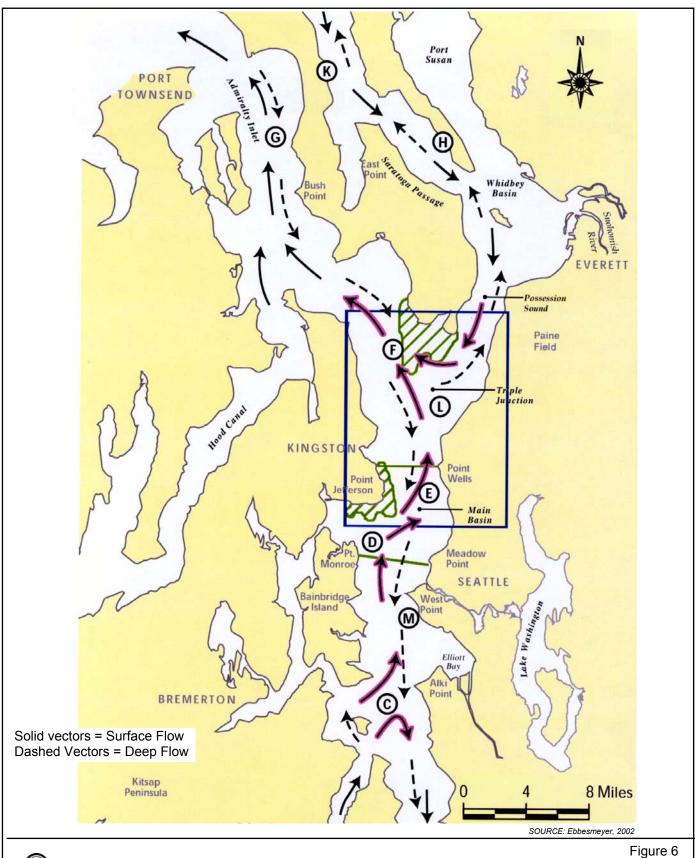**Schematic Circulation in Puget Sound**
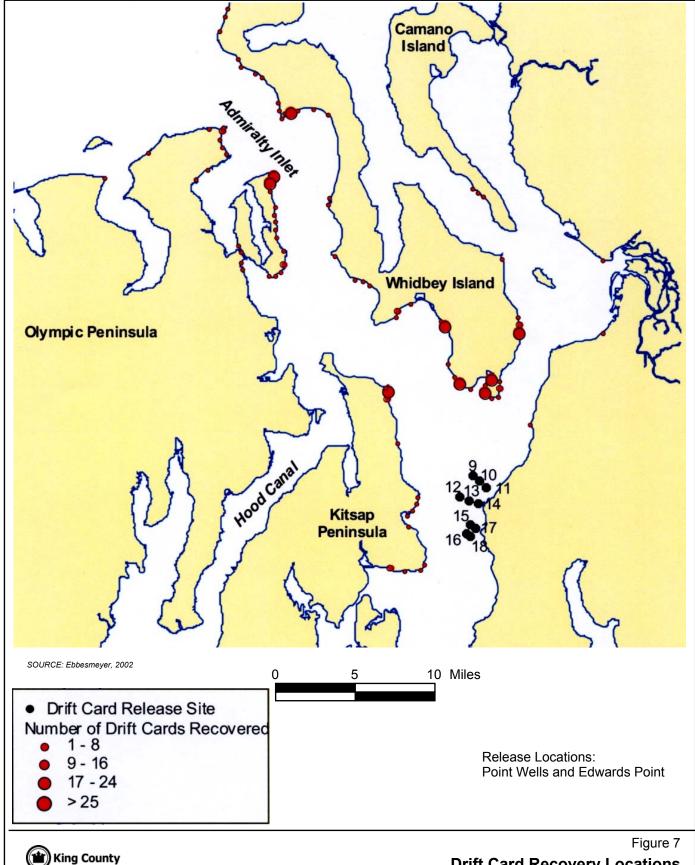*BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM*
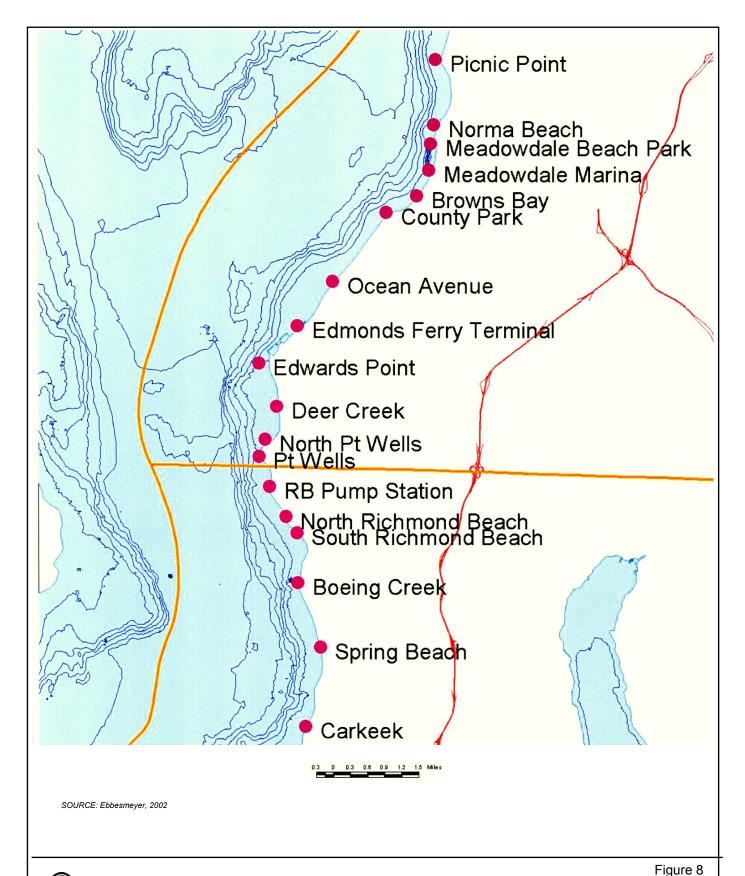
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Department of Natural Resources and Parks
Wastewater Treatment Division

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Camano Island

Admiralty Inlet

Whidbey Island

Olympic Peninsula

Hood Canal

Kitsap Peninsula

9
10
12 13 11
14
15 17
16 18

0   5   10 Miles

● Drift Card Release Site
Number of Drift Cards Recovered
● 1 - 8
● 9 - 16
● 17 - 24
● > 25

Release Locations:
Point Wells and Edwards Point

Figure 7

Drift Card Recovery Locations
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM

Picnic Point

Norma Beach
Meadowdale Beach Park
Meadowdale Marina
Browns Bay
County Park

Ocean Avenue

Edmonds Ferry Terminal

Edwards Point

Deer Creek

North Pt Wells
Pt Wells

RB Pump Station

North Richmond Beach
South Richmond Beach

Boeing Creek

Spring Beach

Carkeek

0.3 0 0.3 0.6 0.9 1.2 1.5 Miles

SOURCE: Ebbesmeyer, 2002

King County
Department of Natural Resources and Parks
Wastewater Treatment Division
File Name: TM09XF0X
Prepared by: Bruce Nairn

Figure 8
Shoreline Sampling Locations for the Dye Studies
BRIGHTWATER REGIONAL
WASTEWATER TREATMENT SYSTEM